EARTH REMOTE SENSING FOR WEATHER FORECASTING AND DISASTER APPLICATIONS

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BACKGROUND

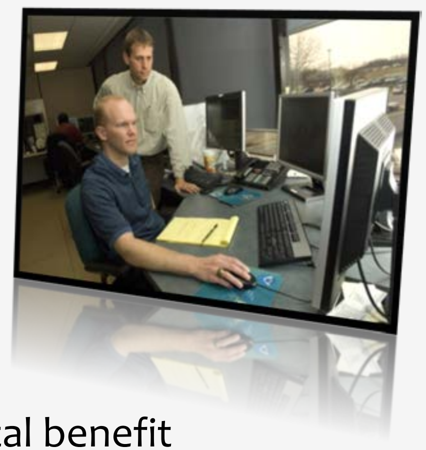
- NASA's constellation of current missions provide several opportunities to apply satellite remote sensing observations to weather forecasting and disaster response applications.
- Examples include:
  - Using NASA's Terra and Aqua MODIS, and the NASA/NOAA Suomi-NPP VIIRS missions to prepare weather forecasters for capabilities of GOES-R.
  - Incorporating other NASA remote sensing assets for improving aspects of numerical weather prediction.
  - Using NASA, NOAA, and international partner resources (e.g. ESA/Sentinel Series) and commercial platforms (high-res, or UAV) to support disaster mapping.

Short-term Prediction Research and Transition (SPoRT) Center

SPoRT is focused on transitioning <u>unique</u> NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale.

- close collaboration with numerous WFOs and National Centers across the country
- SPoRT activities began in 2002, first products to AWIPS in 2003
- co-funded by NOAA since 2009 through satellite "proving ground" activities

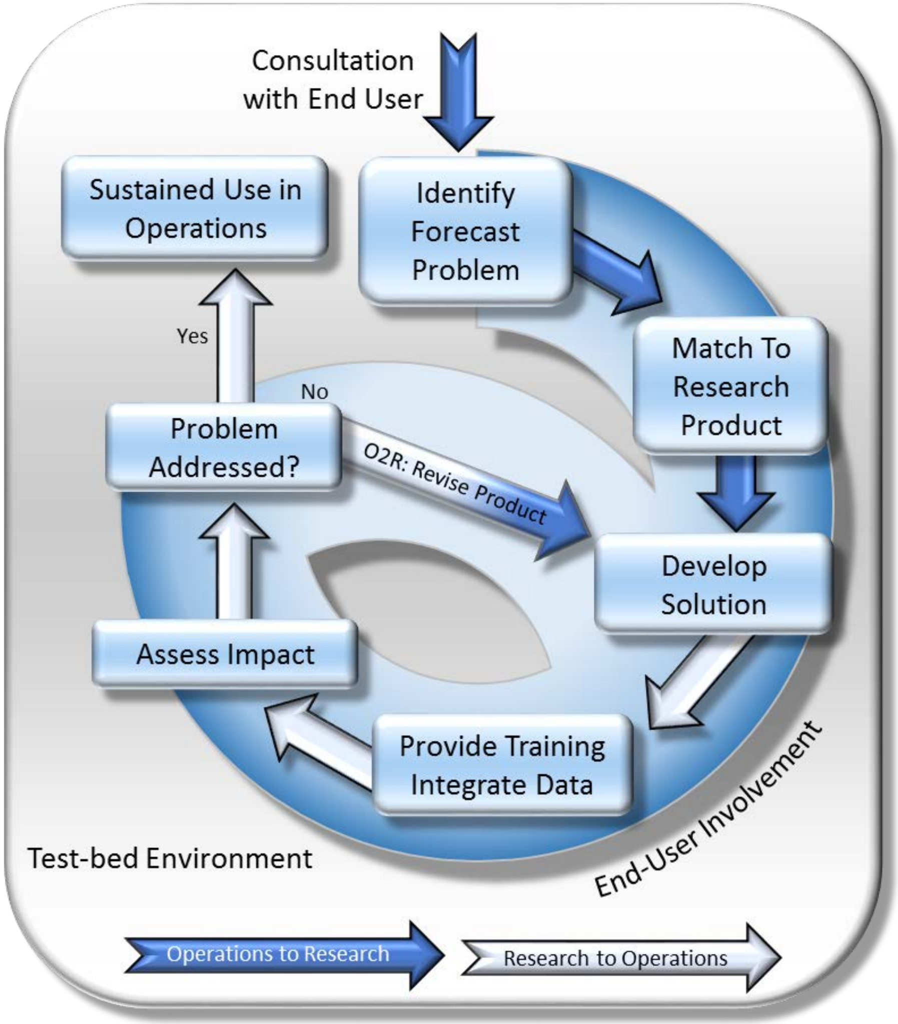
Proven paradigm for transition of research and experimental data to "operations"



<u>Benefit</u>

- demonstrate capability of NASA and NOAA experimental products to weather applications and societal benefit
- prepares forecasters for use of data from next generation of operational satellites (JPSS, GOES-R)

SPoRT Paradigm for R2O and O2R Success



<u>Keys to success</u>

- Involve end user in entire process
- Develop end-user appropriate training
- Assess impact of solution on operations
- Incorporate feedback as part of the O2R process

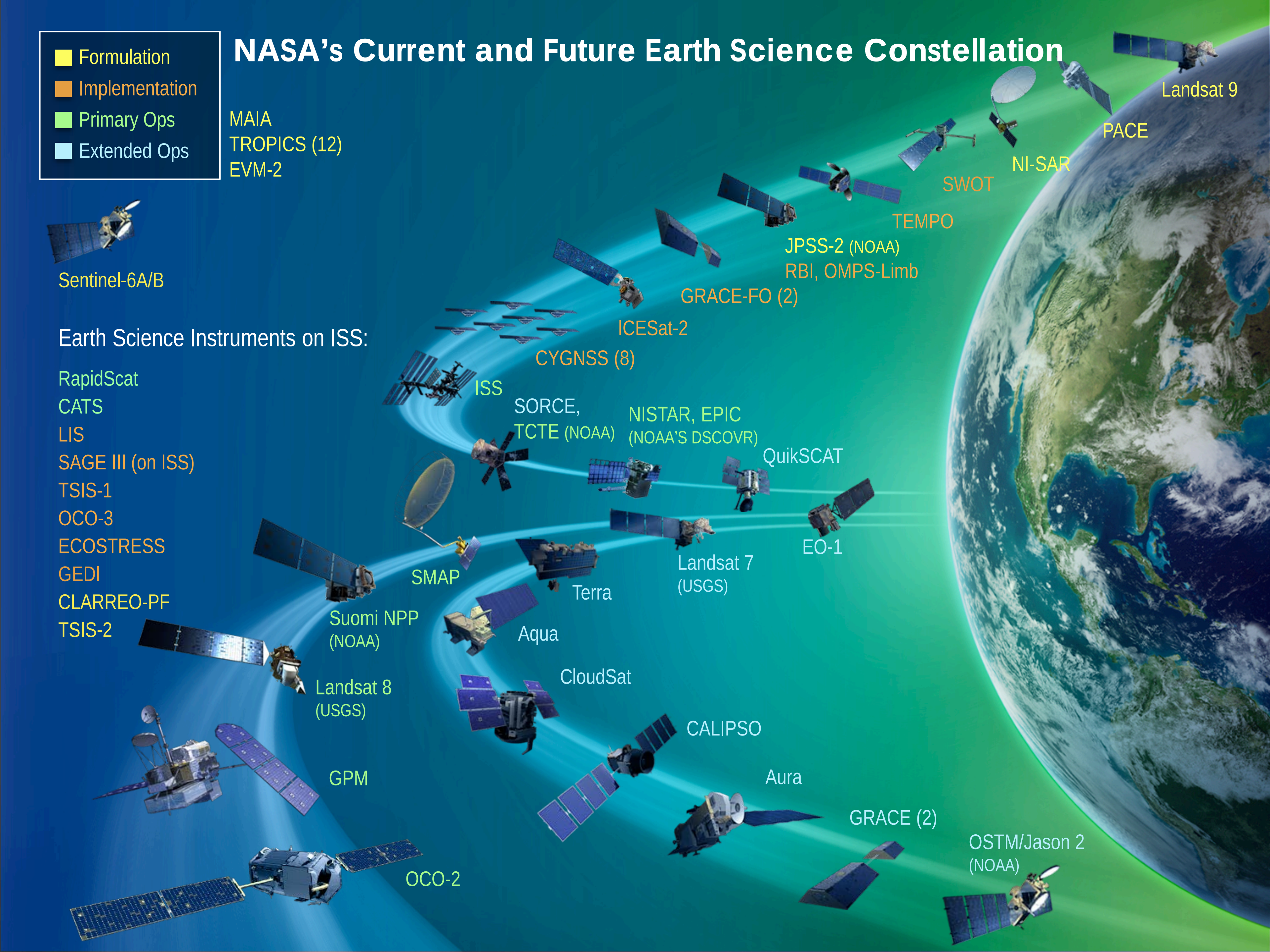
A successful transition occurs when a new capability has a predominately positive impact on the forecast problem and is used “operationally” in the end users decision support system.

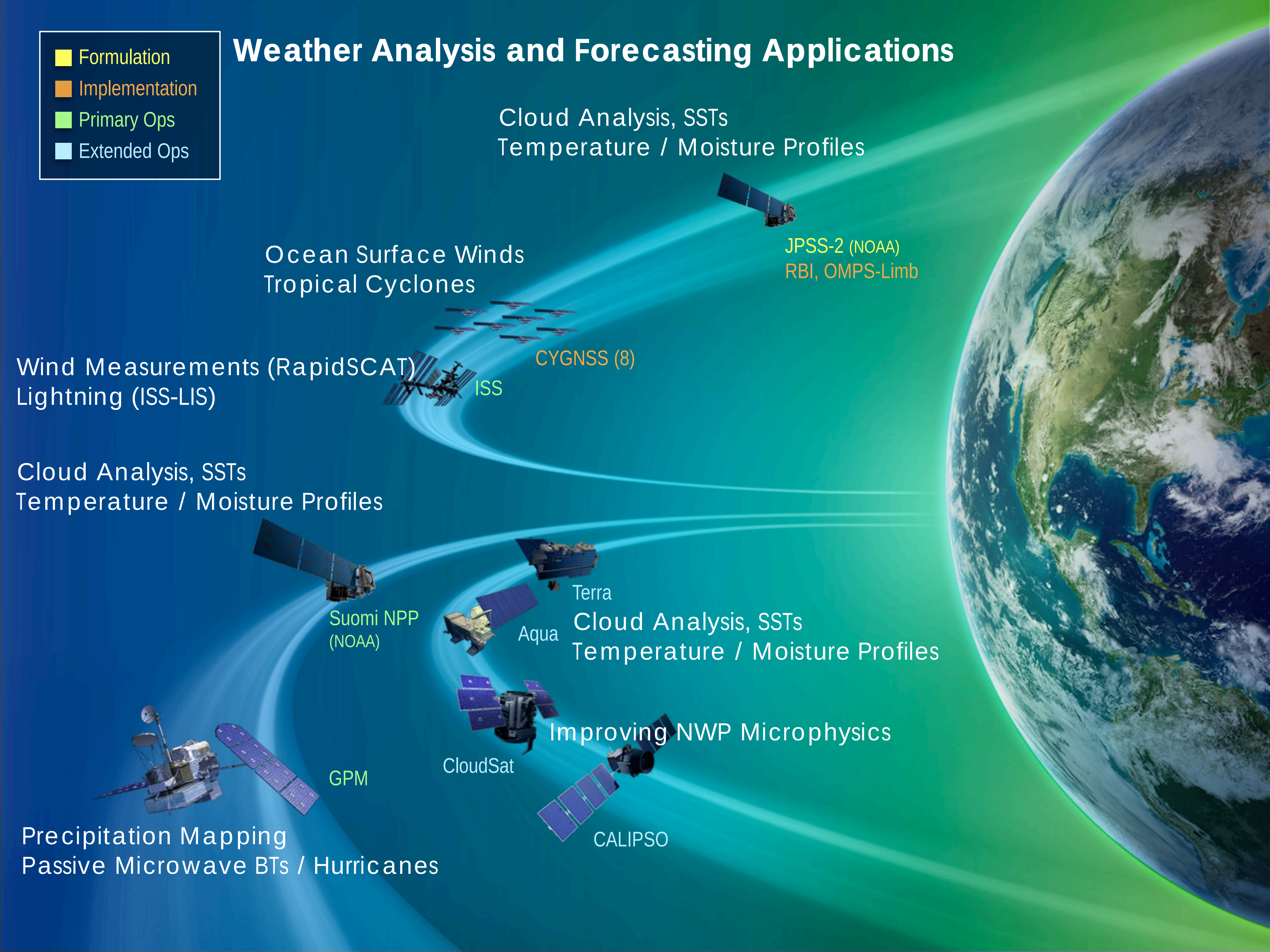
“Operational” use means regular or sustained use of data / products to make decisions

NASA’s Fleet of Earth-Observing Satellites

Not shown: International Space Station, Soil Moisture Active Passive (launched Feb. 2015); TRMM was decommissioned in April 2015

NASA's Current and Future Earth Science Constellation



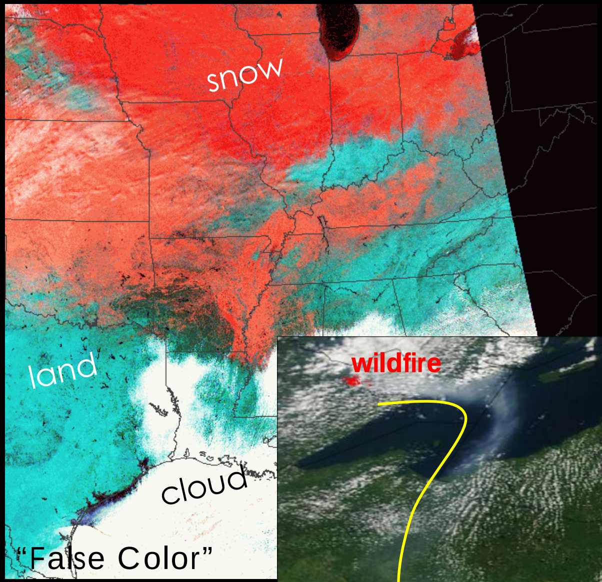


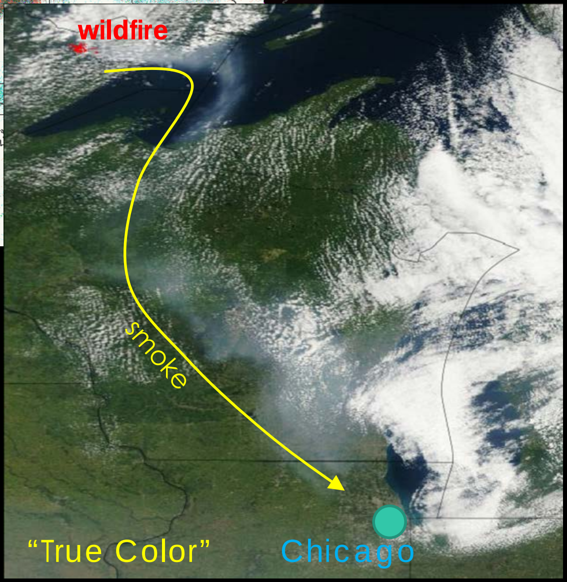
Formulation
Implementation
Primary Ops
Extended Ops
Weather Analysis and Forecasting Applications
Cloud Analysis, SSTs
Temperature / Moisture Profiles
JPSS-2 (NOAA)
RBI, OMPS-Limb
Ocean Surface Winds
Tropical Cyclones
CYGNSS (8)
Wind Measurements (RapidSCAT)
Lightning (ISS-LIS)
ISS
Cloud Analysis, SSTs
Temperature / Moisture Profiles
Suomi NPP
(NOAA)
Terra
Aqua
Cloud Analysis, SSTs
Temperature / Moisture Profiles
Improving NWP Microphysics
CloudSat
GPM
CALIPSO
Precipitation Mapping
Passive Microwave BTs / Hurricanes

MULTISPECTRAL IMAGERY

- Composite satellite imagery provides data fusion of multiple bands into a single image.
  - Specific products for a specific purpose
  - Bands or differences are assigned to each pixel's red, green, and blue intensity.
  - Referred to as an "RGB" product.
- Examples:
  - True Color:
    - Puts the red visible in the red component, green in the green, and blue in the blue. Results in an image of "true color", the way that we would see with our eyes.
  - False Color:
    - Combinations of bands or band differences that create "wrong" colors but those that draw our attention to specific features.
    - Many "false color" products are given names specific to an application and referred to as an "RGB" product.

VIS, N-IR
3 inputs





VIS
3 inputs

AIR MASS RGB

RGB Air Mass Product - What is used in the combine and what does each color represent?

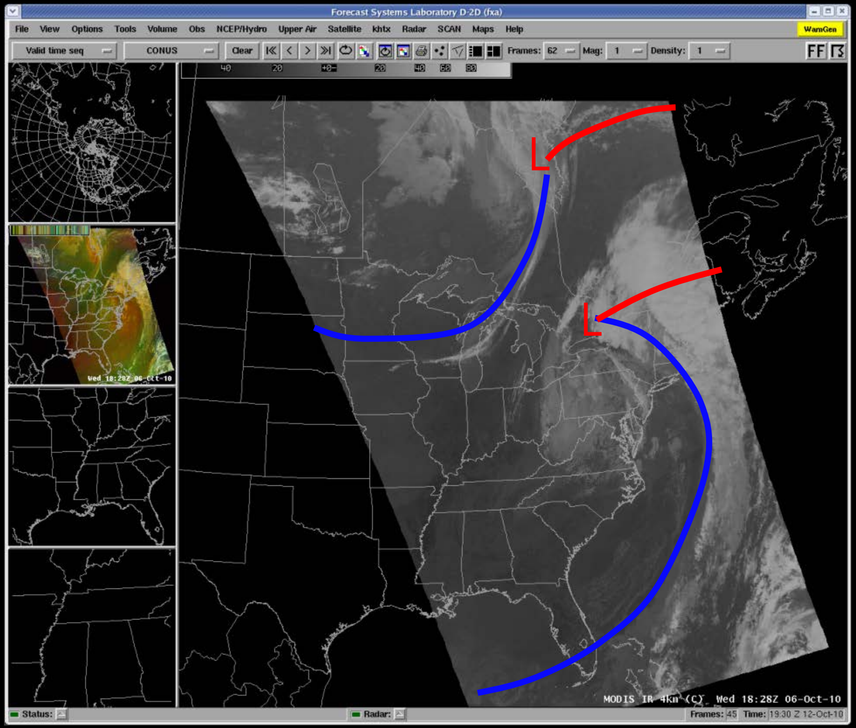
Color	Band / Band Diff.	Physically Relates to….	Little contribution to composite indicates…..	Large contribution to composite indicates …..
Red	**6.7 – 7.3**	Vertical water vapor difference	Moist conditions high levels	Dry conditions at high levels
Green	**9.7- 10.7**	Estimate of tropopause height based on ozone. Polar (tropical) air has higher (lower) ozone concentrations	Tropopause height is low. Typically indicates a polar air mass, where 9.7 has very cold brightness temperature compared to 10.7	Tropopause height is high. Likely a tropical air mass where the two channels will have similar brightness temperature values
Blue	**6.7**	Water Vapor in layer from ~200 – 500 mb	Dry at upper levels Warm brightness temperatures have little blue	Moist at upper levels Cold brightness temperatures result in lots of blue

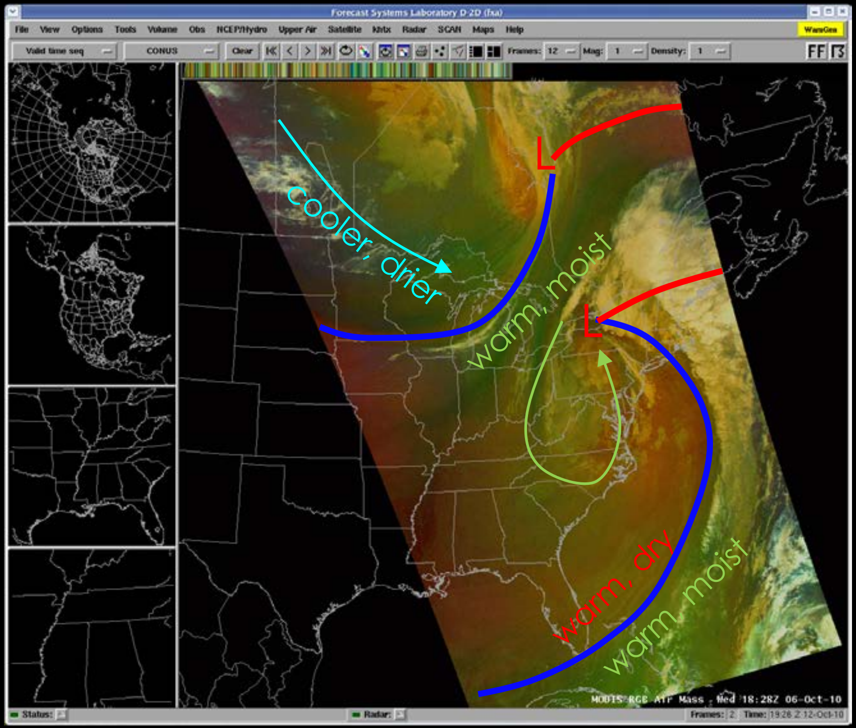
The Air Mass RGB was designed by EUMETSAT for their Meteosat/SEVIRI instrument to highlight synoptic-scale features, such as contrasts of warm/cold air associated with strong fronts, differences in moisture content, and other large-scale features.

AIR MASS RGB

Single Channel Water Vapor – Features

"Air Mass" – Feature Detection





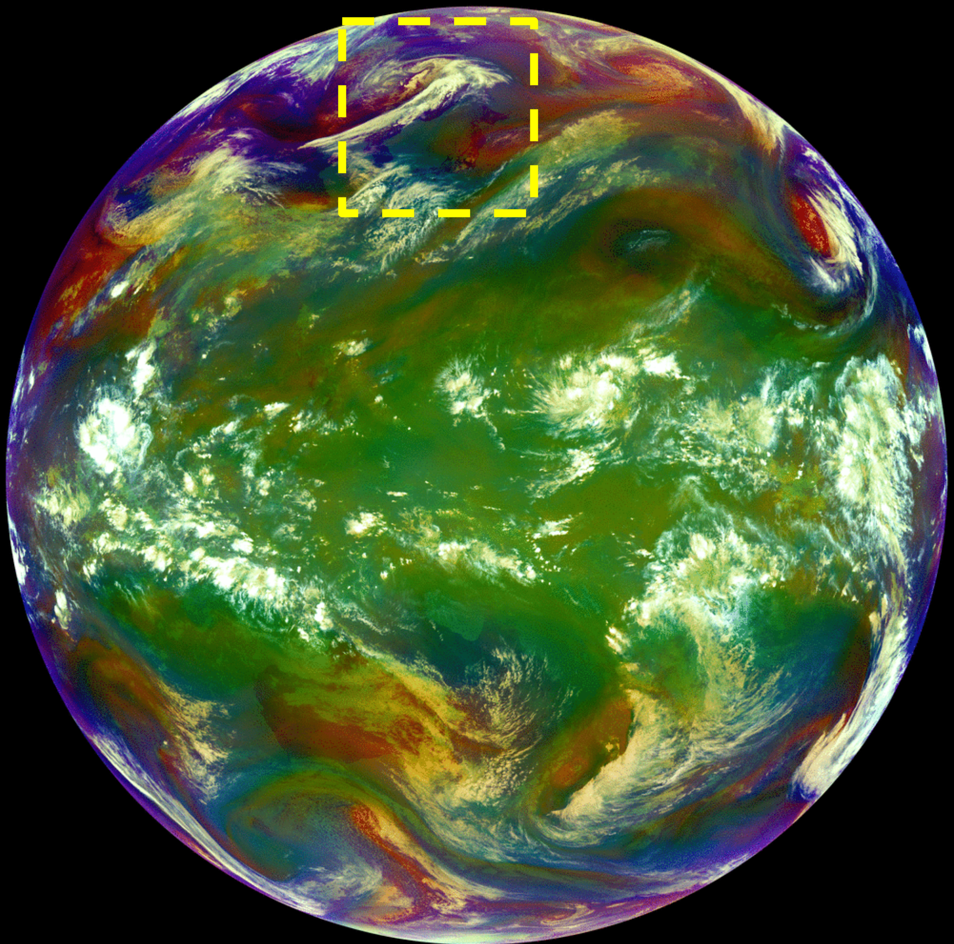
Single Channel Water Vapor – Features

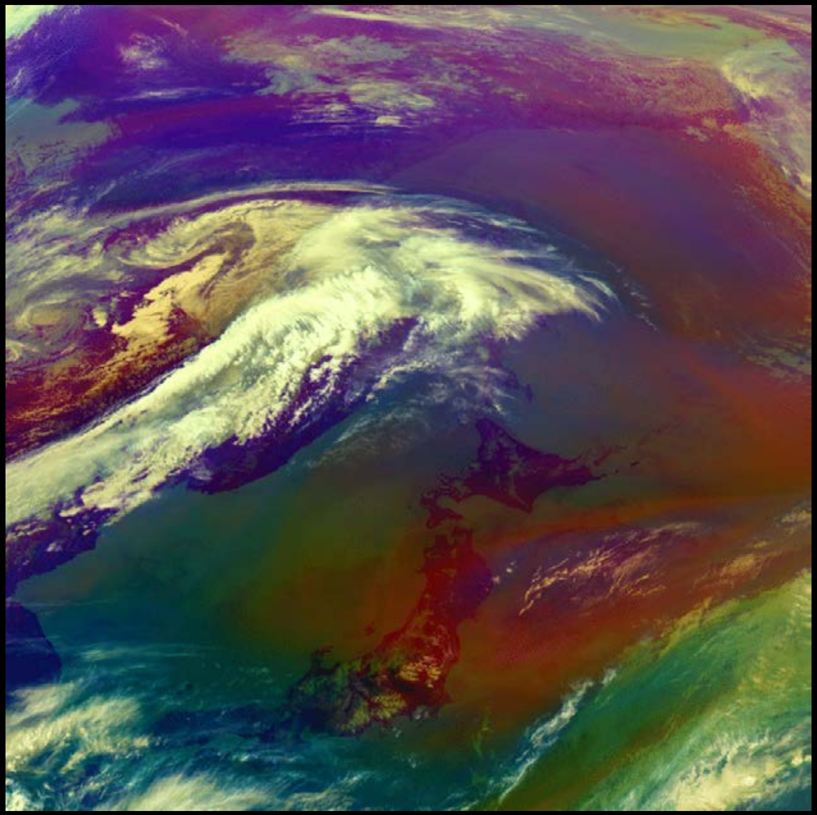
R: 6.2 µm-7.3 µm, G: 9.7 µm-10.8 µm, B: 6.2 µm

Combines 4 channels of information.

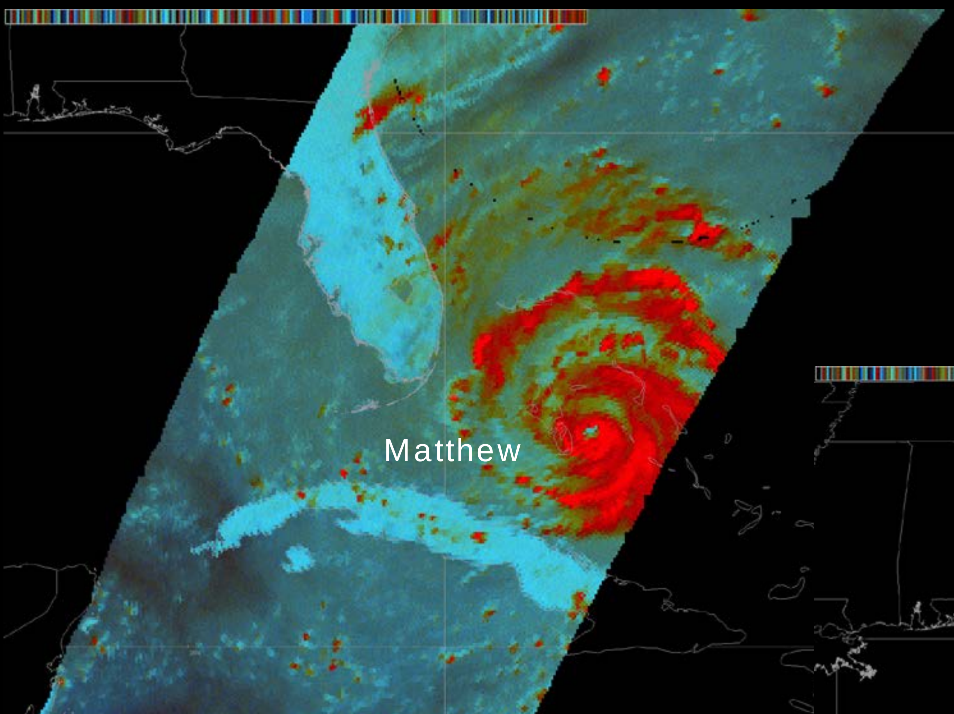
AIR MASS RGB

JAPAN'S HIMAWARI-8/AHI (PROXY FOR GOES-R)

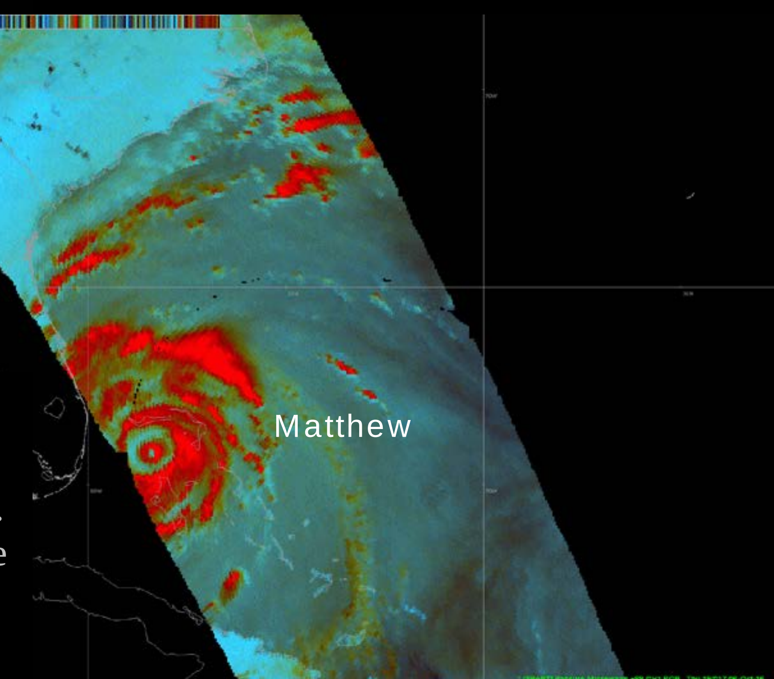




PASSIVE MICROWAVE



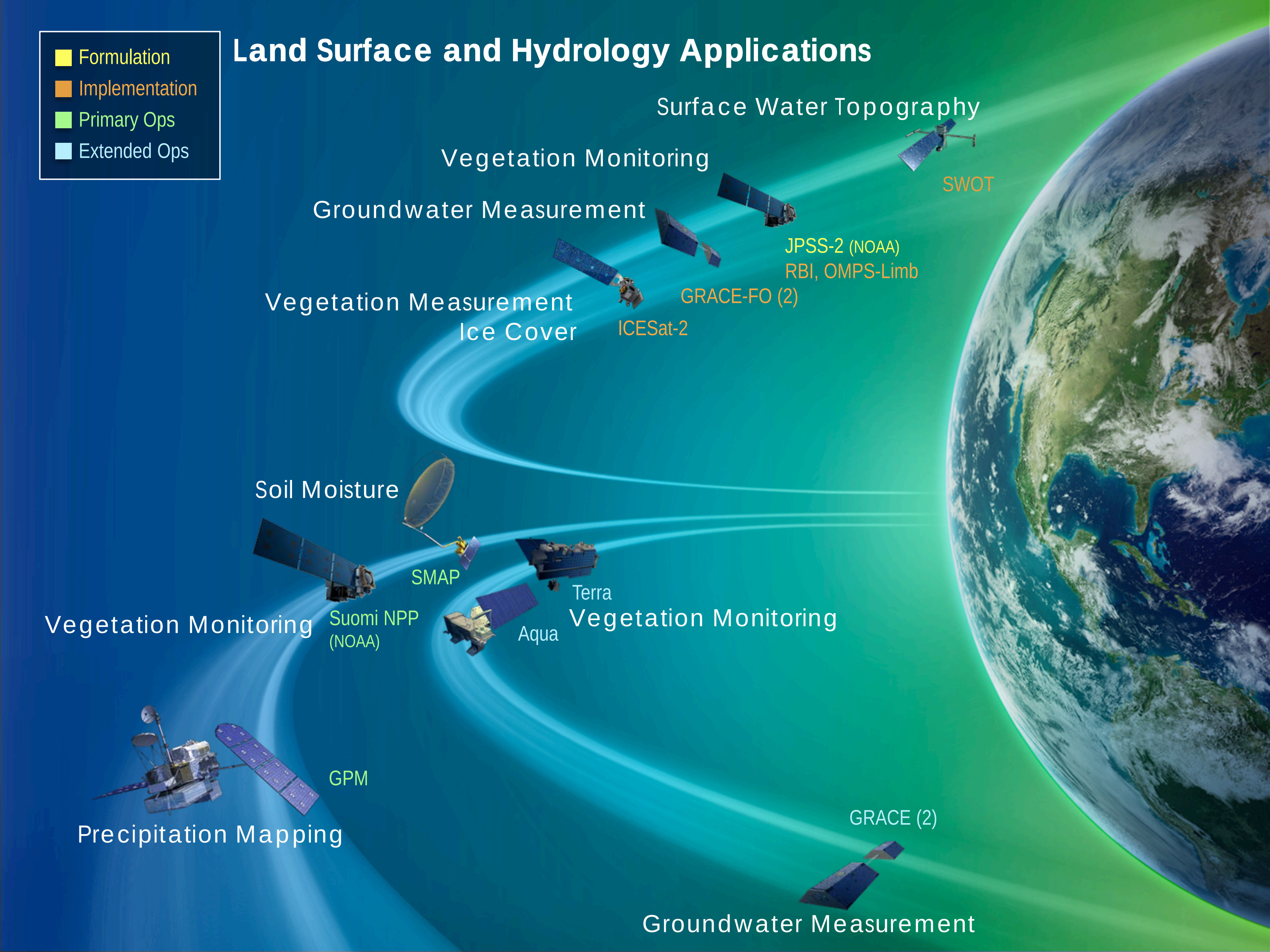
The Global Precipitation Measurement (GPM) mission provides cross-calibration of a broad suite of passive microwave sensors, allowing for generation of false color products helpful to identify the center of tropical cyclone circulations.



Hurricane Matthew approaches the eastern coast of Florida on 10/6 at 9 and 19 UTC, shown in false color composite from the GPM GMI. These products are provided to the NOAA/NWS/National Hurricane Center in their AWIPS/N-AWIPS support system.

PRECIPITATION MAPPING

Progress of Hurricane Matthew from geostationary along with GPM Observations


Land Surface and Hydrology Applications
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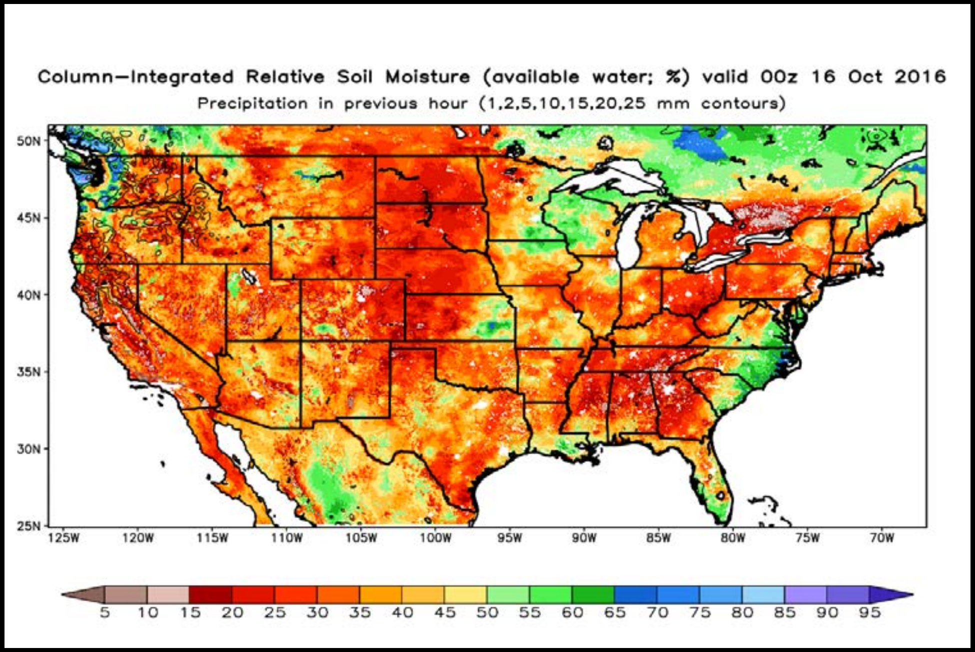
Implementation
Primary Ops
Extended Ops
Surface Water Topography
SWOT
Vegetation Monitoring
JPSS-2 (NOAA)
RBI, OMPS-Limb
Groundwater Measurement
GRACE-FO (2)
Vegetation Measurement
Ice Cover
ICESat-2
Soil Moisture
SMAP
Vegetation Monitoring
Suomi NPP
(NOAA)
Terra
Aqua
Vegetation Monitoring
GPM
Precipitation Mapping
GRACE (2)
Groundwater Measurement

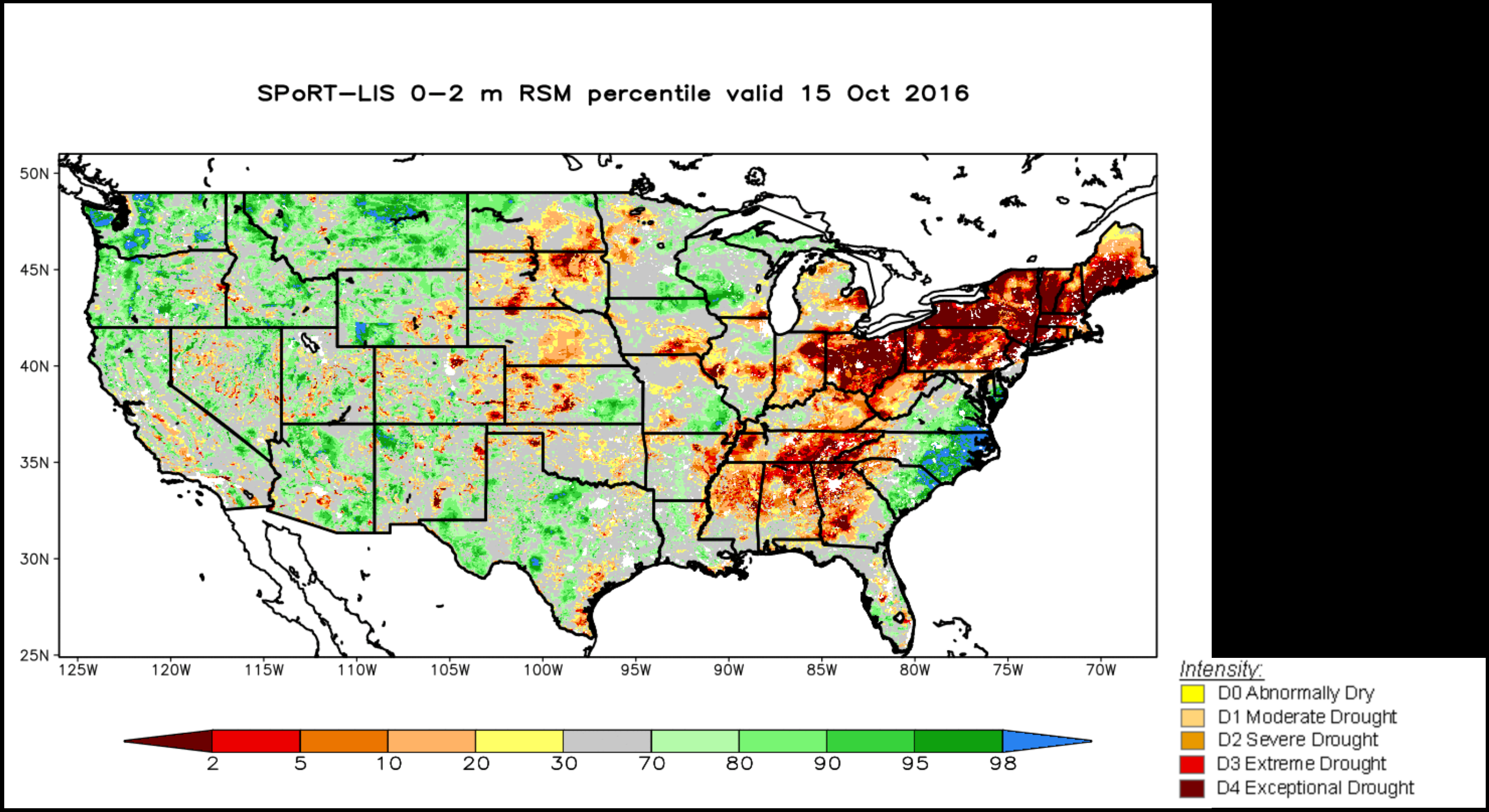
LAND INFORMATION SYSTEM

- The NASA Land Information System (LIS) allows for streamlined data assimilation and integration of various land surface models.
- Real-time daily LIS integration includes:
    - Precipitation forcing from GDAS/Stage IV or GFS (forecasts)
    - VIIRS vegetation
    - SMAP soil moisture



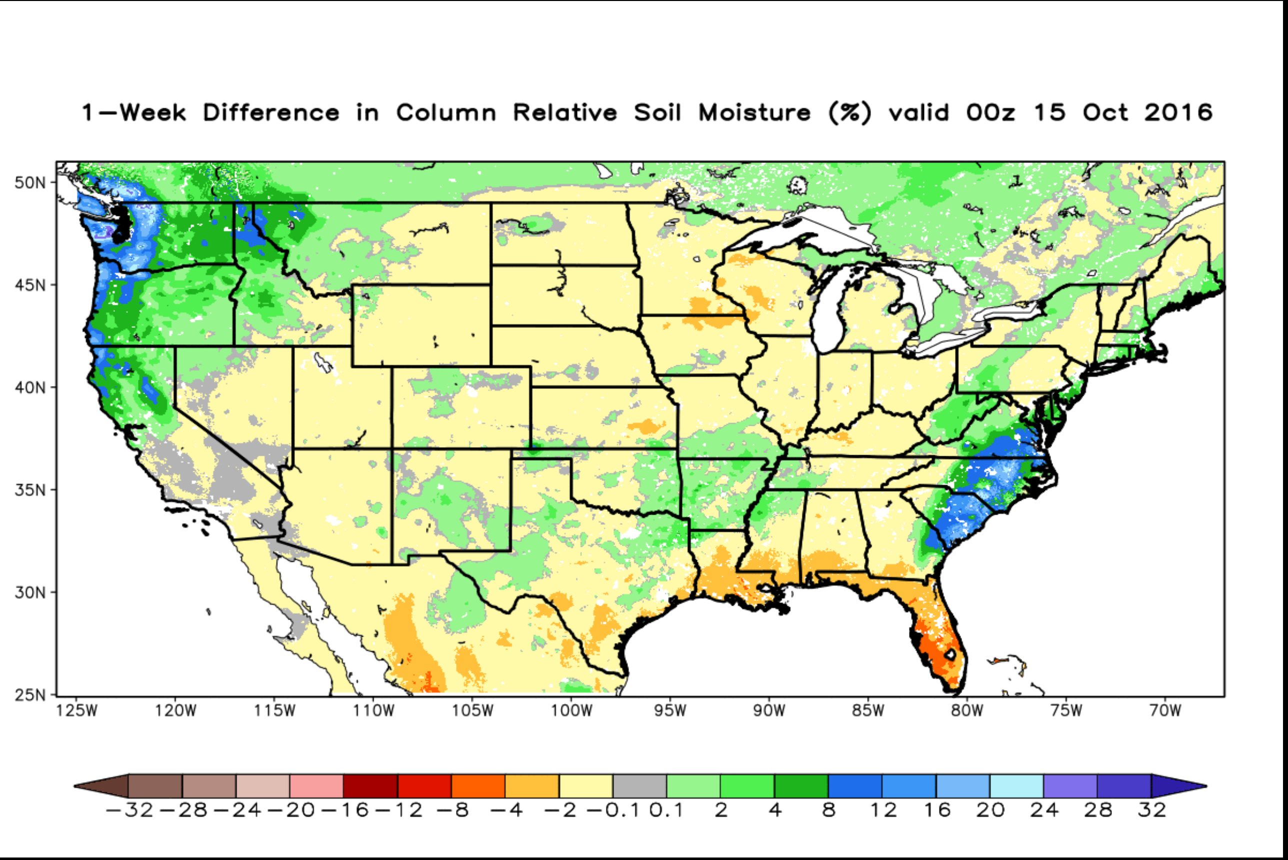
Column-integrated (0-2m) relative soil moisture (0% dry, 100% saturated) across the CONUS LIS real-time domain, from 16 October 2016.

DROUGHT APPLICATIONS



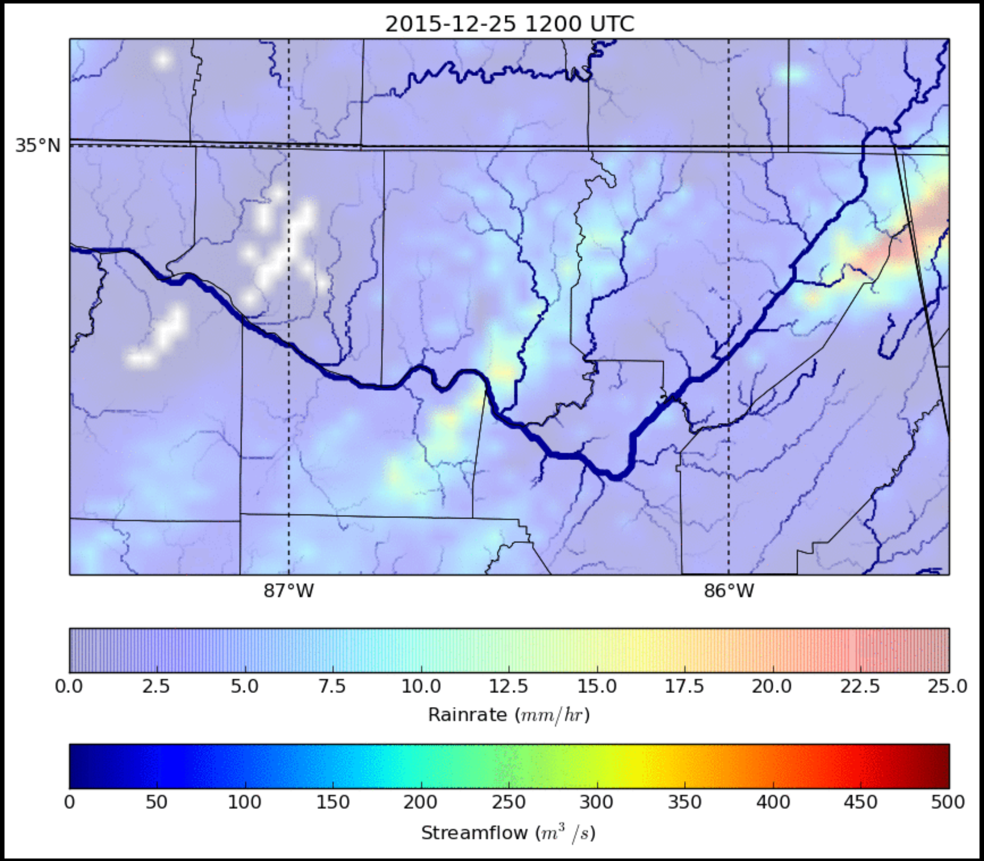
Current data compared to a 30-year climatology run give percentiles to rank current conditions and track fairly well with Drought Monitor categories, especially east of the Rockies.

DROUGHT APPLICATIONS

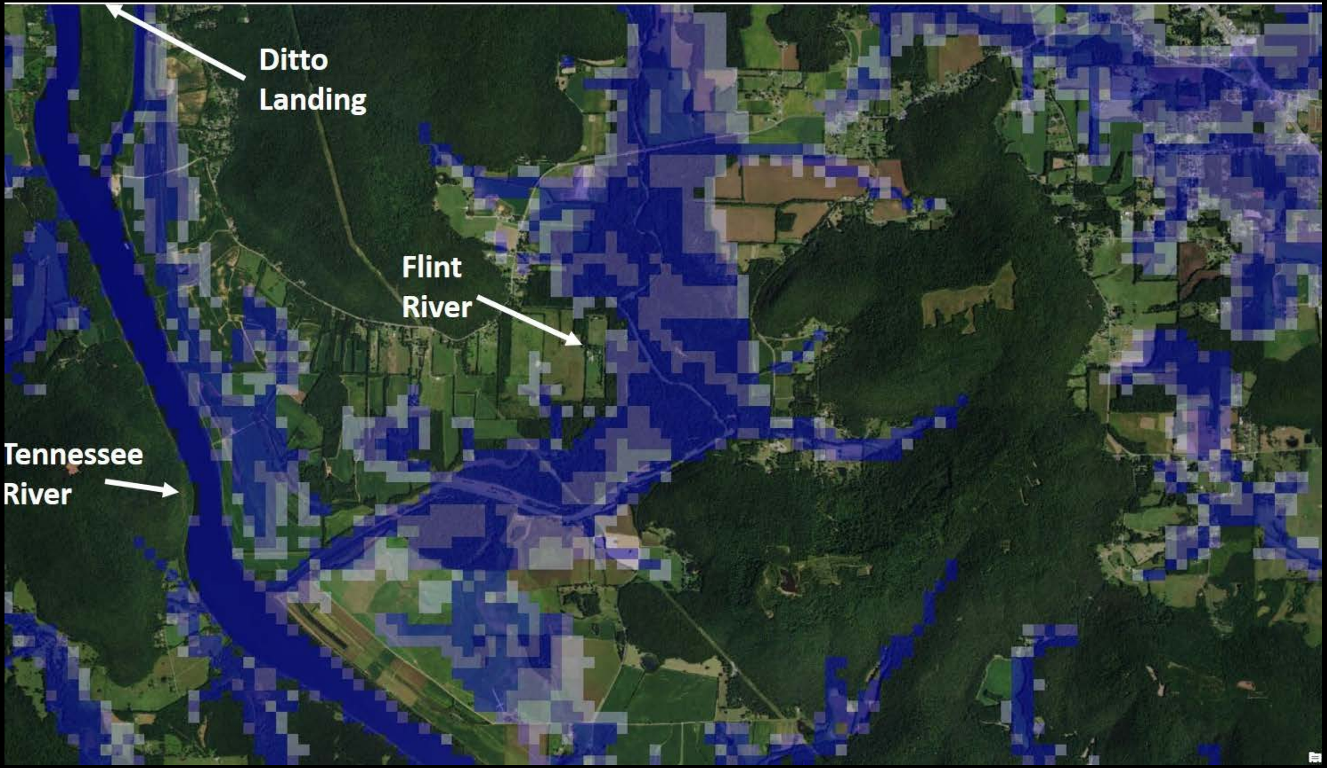


FLOODING

- Collaborations with the NWC have enabled local configuration of National Water Model (NWM)
- NASA has many current and near-future missions focused on ground/surface water and land use that could improve hydrologic modeling
- Data assimilation with the Land Information System and other procedures may be beneficial for improving streamflow in the NWM and predictions of inundation.



FLOODING



National Water Model outputs can be used to estimate likely flood extent. Here, an idealized scenario of ~6ft. Above stage for affected rivers implies widespread inundation in N. Alabama. Satellite imagery can be used to help with validation, along with Civil Air Patrol and NOAA collections.

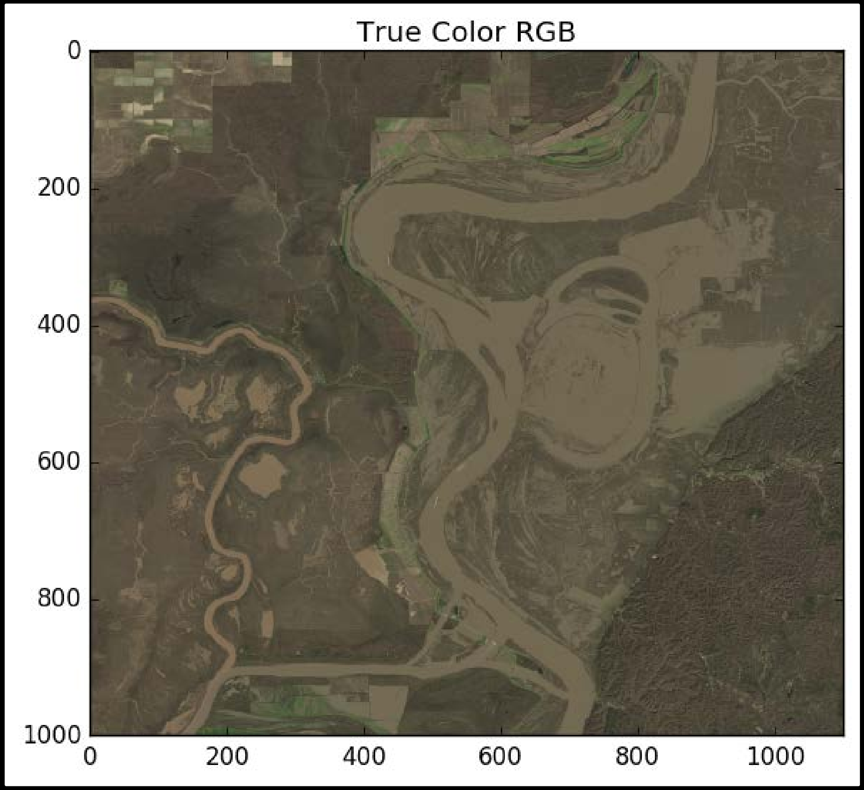
Disaster Response and Recovery Applications

FLOOD MAPPING

- Visible and near-infrared reflectance is helpful for monitoring the occurrence and extent of flooding, though observations can be obstructed by cloud cover associated with the rainfall event.
  - Examples: Identifying water extent and coverage from VIIRS, MODIS, Landsat-7/8, EO-1, commercial data
- Synthetic Aperture Radar (SAR) allows for a view through clouds, as long as there is not intense rainfall occurring at the time of observation.
  - Sentinel-1A/1B provide snapshots every six days, and other commercial providers available.
  - SAR capabilities coming from NASA NISAR in 2020+

FLOOD MAPPING

- Goals:
  - Acquire sufficient pre-event scenes to train a machine learning algorithm (classifier) to reliably separate water from land/vegetation.
  - For a flooded scene, perform the classification and compare against a reference water layer.
  - Identify "new" water as potential/likely flood



Landsat-8 scene of Mississippi River flooding in early January 2016 and Python-based machine learning / classification of flood extent.

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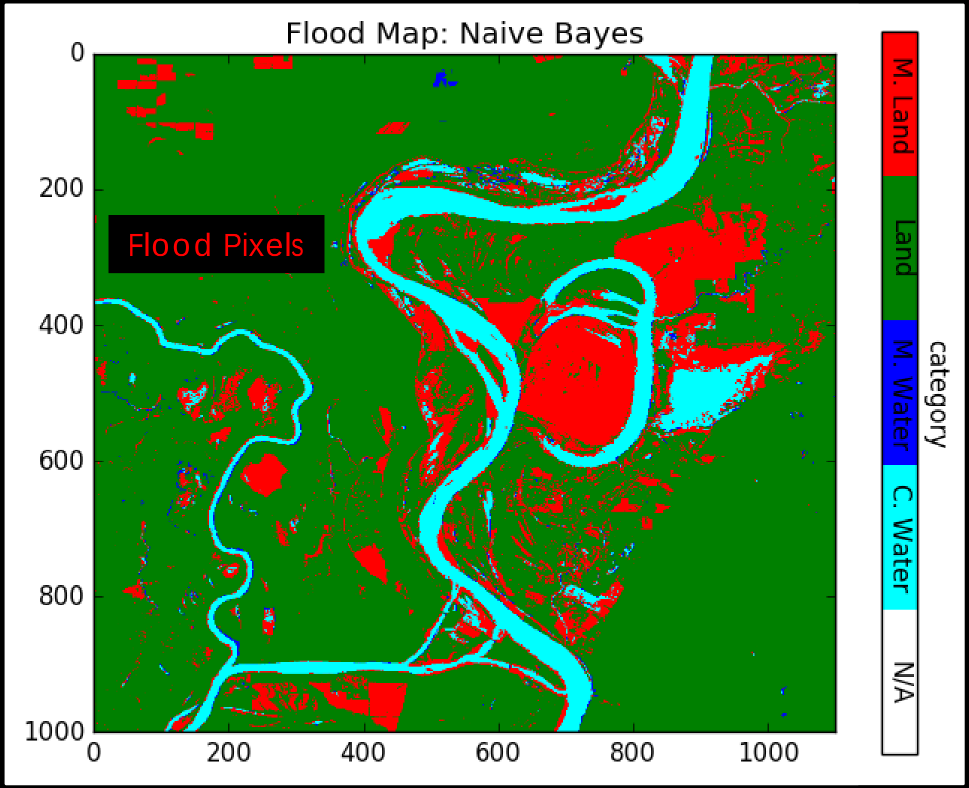


Landsat-8 scene of Mississippi River flooding in early January 2016 and Python-based machine learning / classification of flood extent.

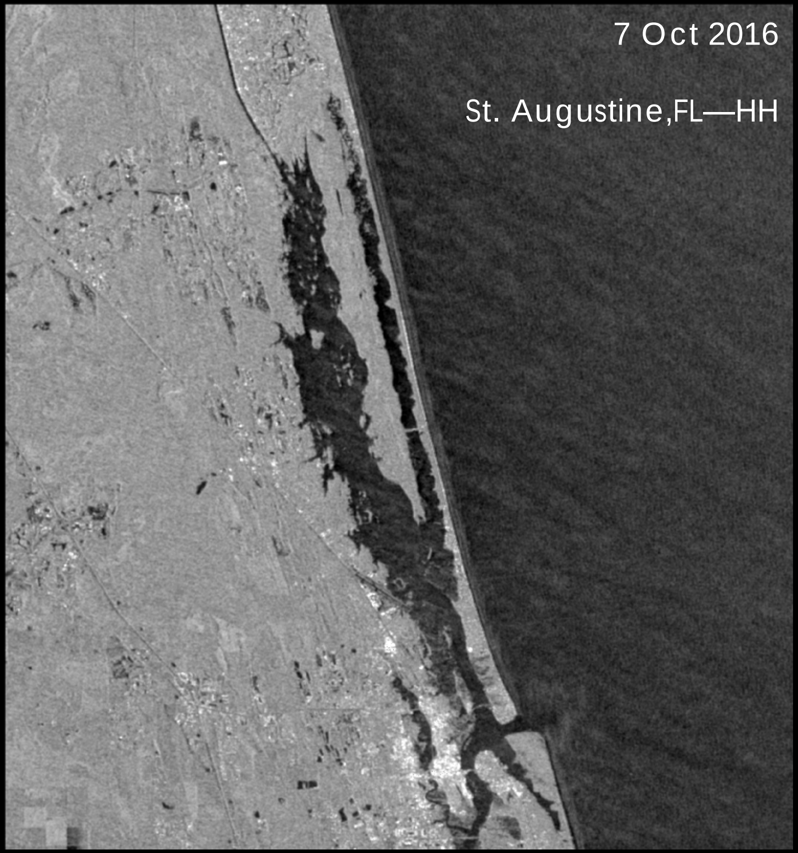
FLOOD MAPPING

- SAR offers additional benefits of being able to penetrate through cloudy scenes, useful for post-storm mapping.
- Here, products acquired following Hurricane Matthew highlight changes in water along the Florida coastline associated with surge and rainfall.

Radarsat-2 HH-pol backscatter of the St. Augustine, FL area pre-Matthew on 10 September 2016.

FLOOD MAPPING

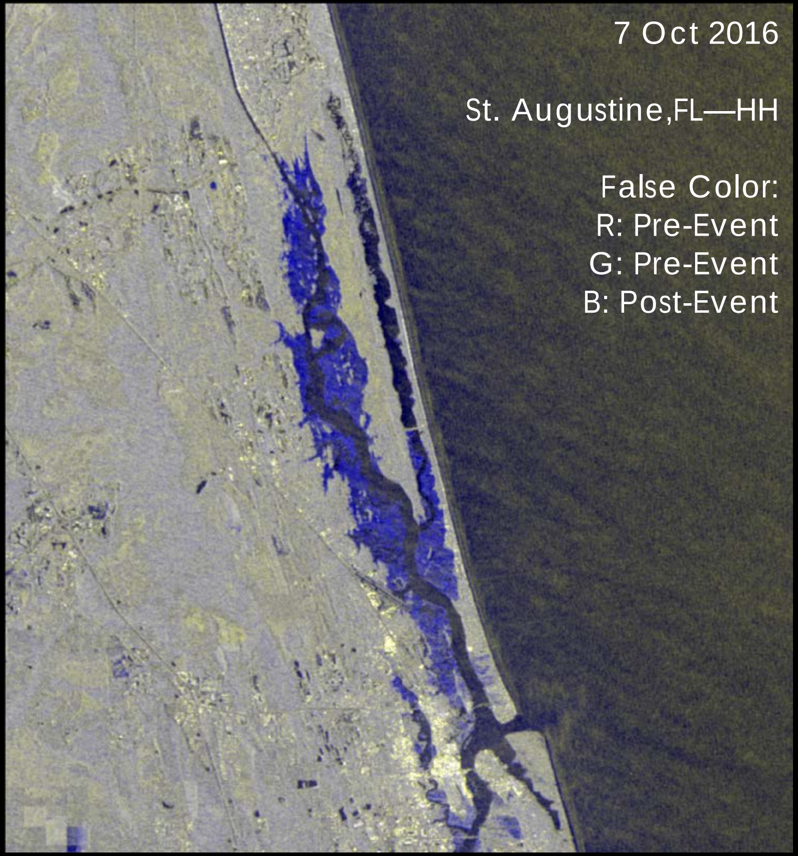
- Water returns a lower backscatter, resulting in darker appearance when the pre- and post-event scenes are given the same B/W stretch.
- The expansion of the dark areas inland highlight broader water extent near St. Augustine in this imagery from Radarsat-2



Radarsat-2 HH-pol backscatter of the St. Augustine, FL area post-Matthew on 7 October 2016.

FLOOD MAPPING

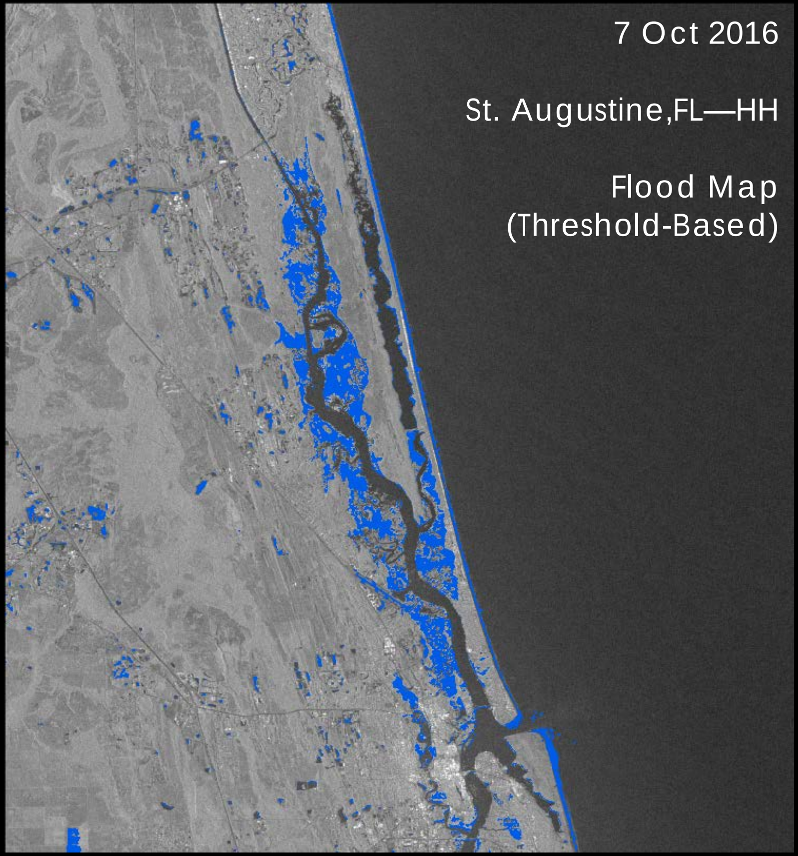
- Similar to VIS/NIR/IR applications of false color composites, pre- and post-event scenes can be compared to highlight change.
- Here, pre- and post-event scenes are given a common stretch.
- Increases in blues associated with expansion of water, while yellows (particularly over the ocean, with waves) are due to other increases in post-event backscatter.



False-color composite of pre- and post-event scenes, highlighting decrease in backscatter (water) in blue.

FLOOD MAPPING

- Finally, the post-event scene can be used to extract flood extent by comparing water to a pre-event reference water layer.
- Water is relatively dark, and a histogram can be built to help separate values associated with water and land.
- Here, a threshold value is used to map water and flood extent.



Flood extent based upon extraction of pixels below a selected post-event backscatter threshold (blue).

FLOOD MAPPING

- Second example – using the Sentinel 1A SAR instrument and focusing on an area near Lumberton, North Carolina.
- Pre-event scene has some small areas of water (dark) along with terrain features.

Sentinel-1A backscatter over the Lumberton, NC area, taken pre-Matthew on 29 September 2016. Darkest areas correspond to water.

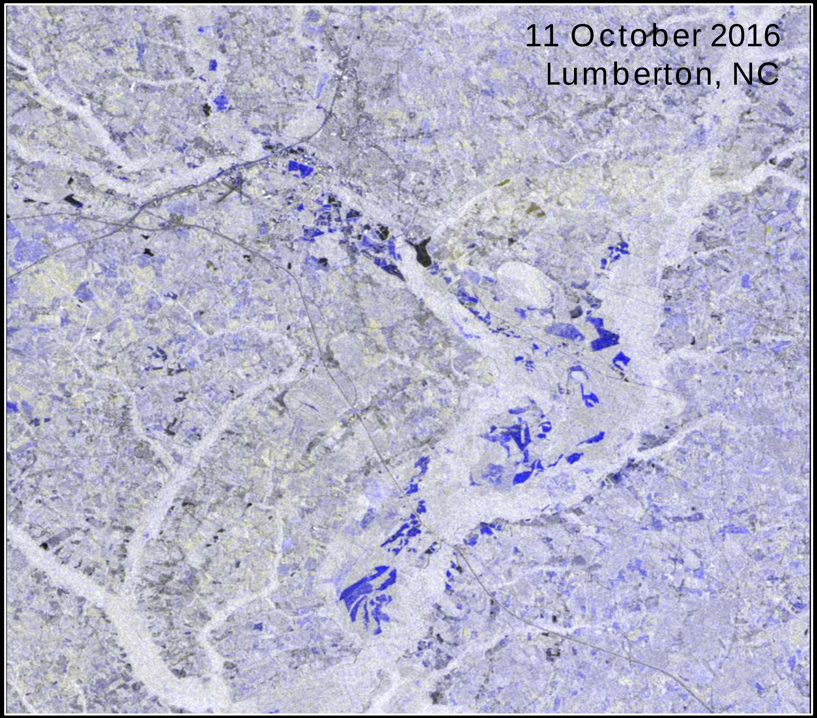
FLOOD MAPPING

- Post event, darker areas persist where water has expanded, while most of the surrounding vegetation and land features provide a similar backscatter.

Sentinel-1A backscatter over the Lumberton, NC area, taken post-Matthew on 11 October 2016. Additional dark areas correspond to post-storm water and flood.

FLOOD MAPPING

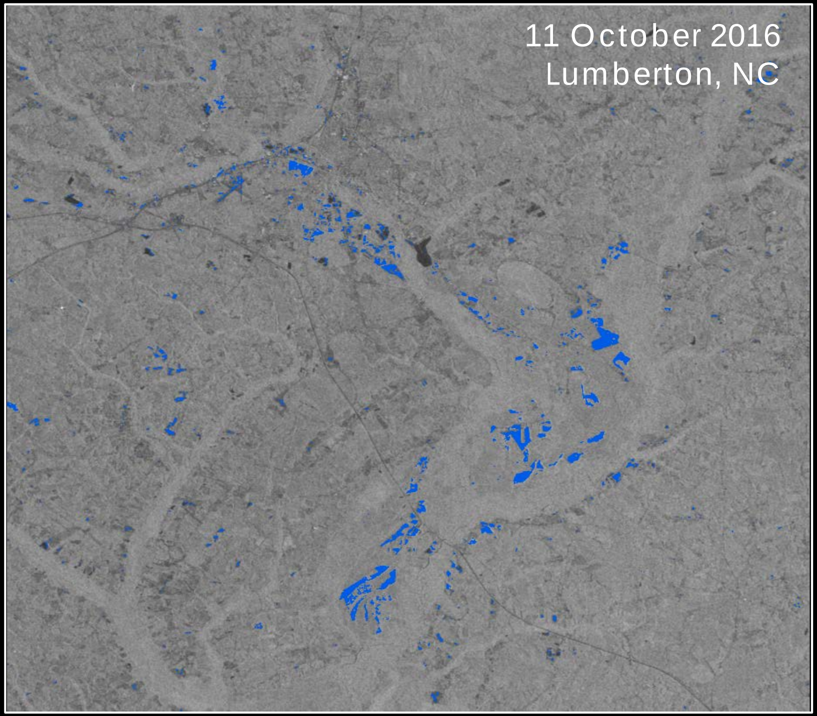
- False color of the pre- and post-event scenes capture a wide area of light blue associated with decreased backscatter from change in vegetation/viewing angle.
- Small pockets of more intense blue highlight change from land to water.



False color composite of pre- and post-event scenes, highlighting decreases in backscatter (increases in water) as shades of dark blue.

FLOOD MAPPING

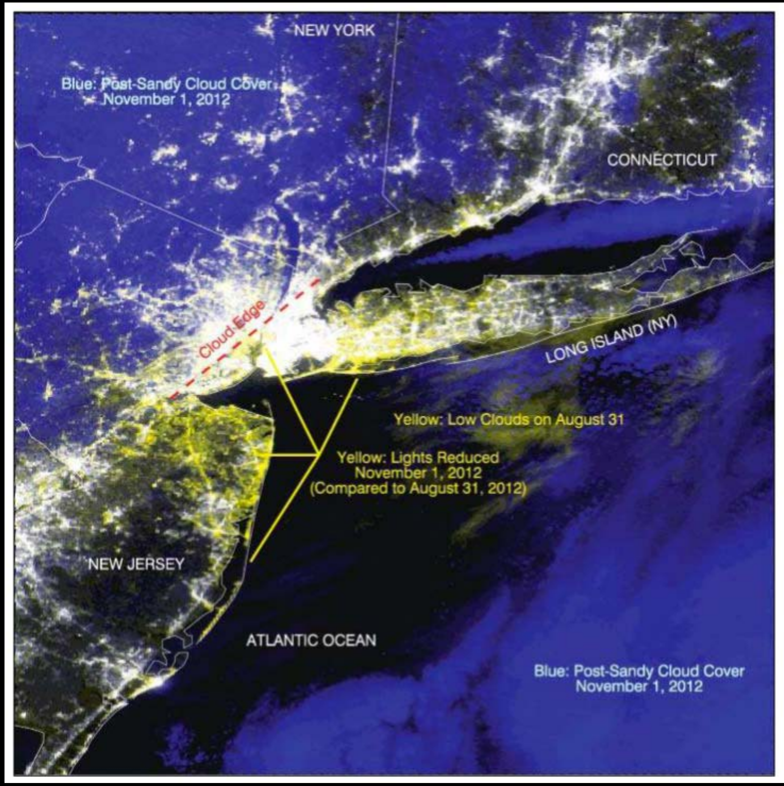
- Threshold-based selection to identify water bodies and compare against pre-event scene reveals flood pixels that can be extracted and mapped with GIS and other software.



Threshold-based flood identification from the post-event scene, with flood areas highlighted in blue.

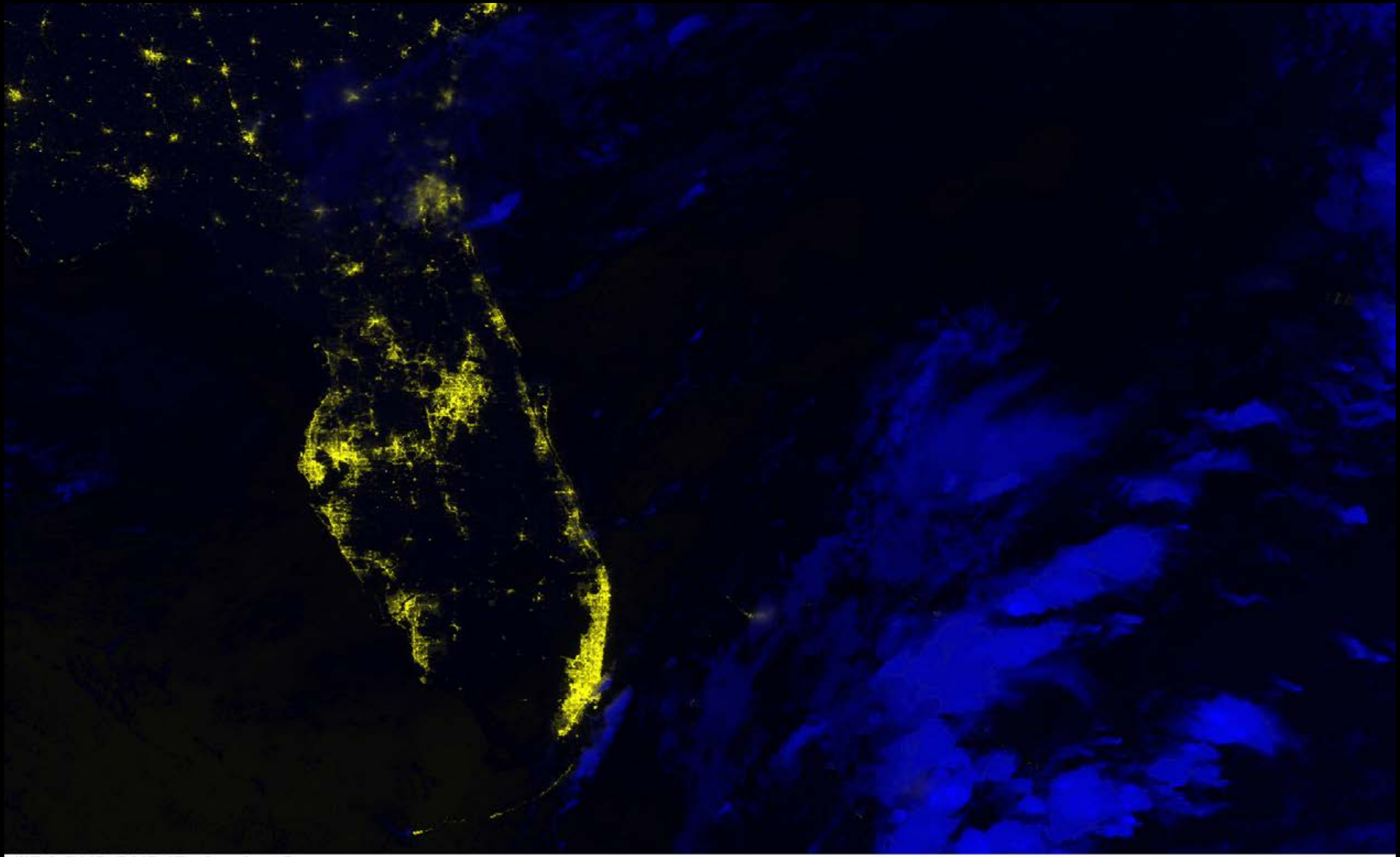
POWER OUTAGES

- The NASA/NOAA Suomi-NPP mission provides the VIIRS instrument, which has a Day-Night band sensing light emission from cities, fires, moonlit clouds and the surface, and other features.
- Monitoring changes in the DNB can be helpful to identify power outages and recovery.



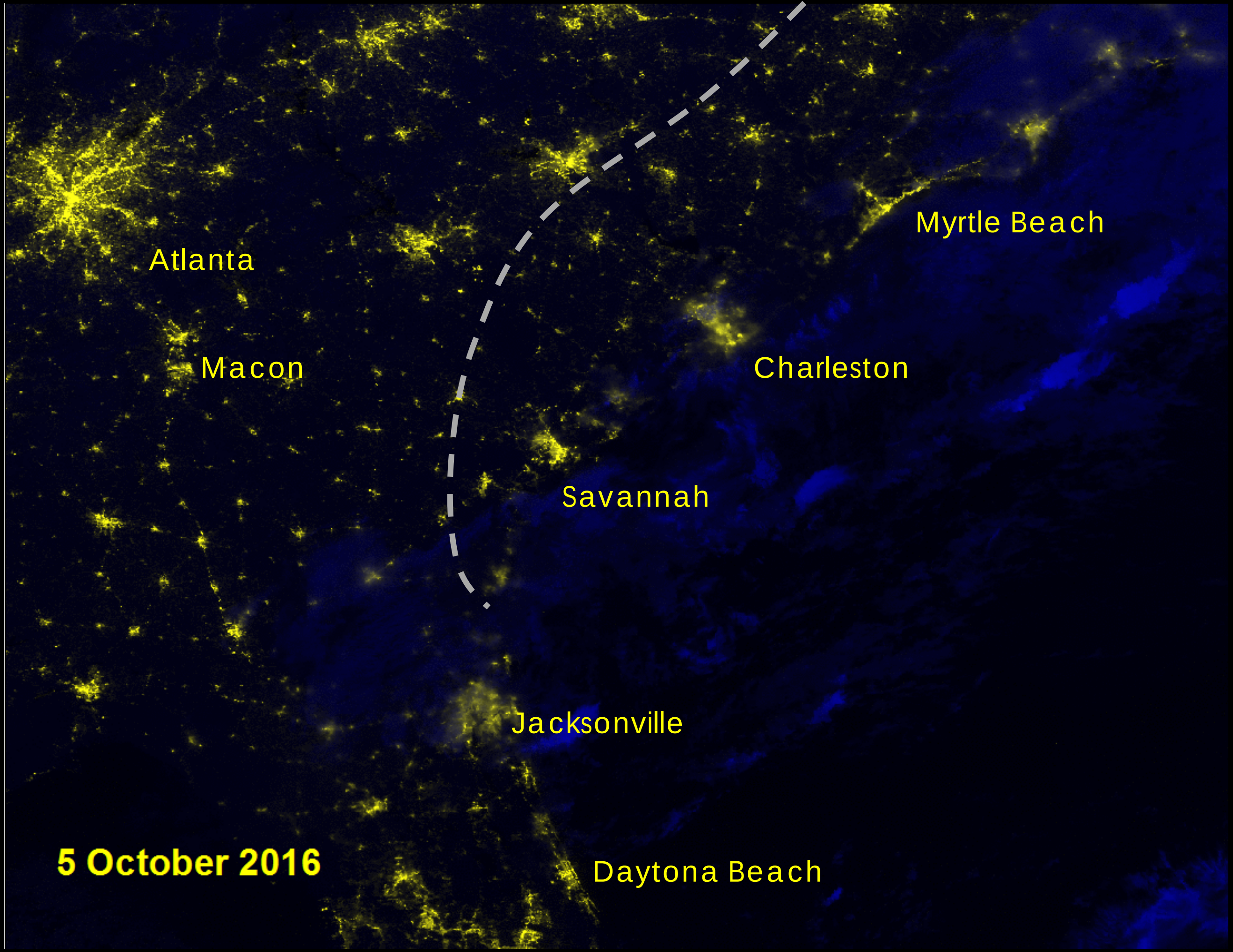
False color depiction of power outages (yellow) and moonlit cloud cover (blues) following Hurricane Sandy (reproduced from Molthan and Jedlovec 2012).

POWER OUTAGES



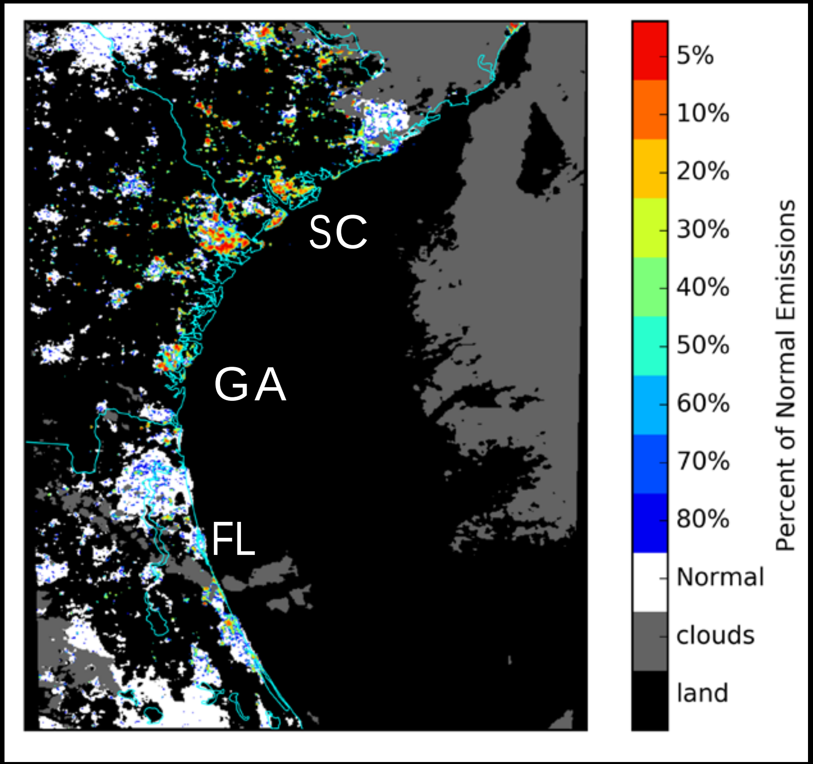
VIIRS DNB-DNB-IR: October 5

POWER OUTAGES



POWER OUTAGES

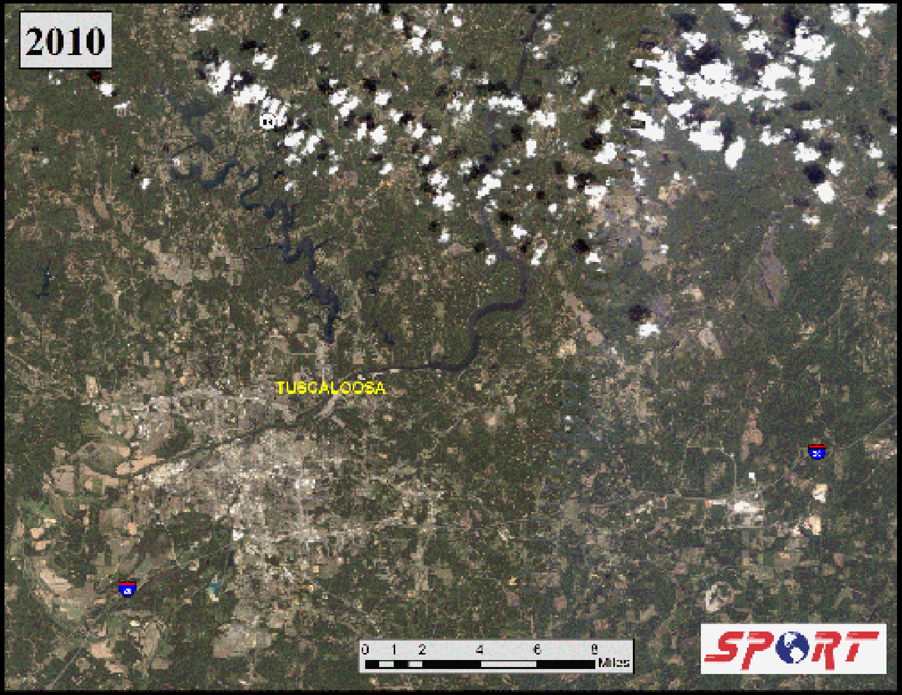
- In addition to false color compositing and visual interpretation, quantitative differencing from pre- and post-event scenes can be helpful in cloud-free conditions.
- Differences in pre- and post-Matthew light emissions from the Florida coastline and Carolinas shown from the VIIRS DNB.



Percent of pre-event (“normal”) light from October 5 (normal) to October 9 (post-Matthew) for northeastern FL and the Carolinas.

SEVERE WEATHER

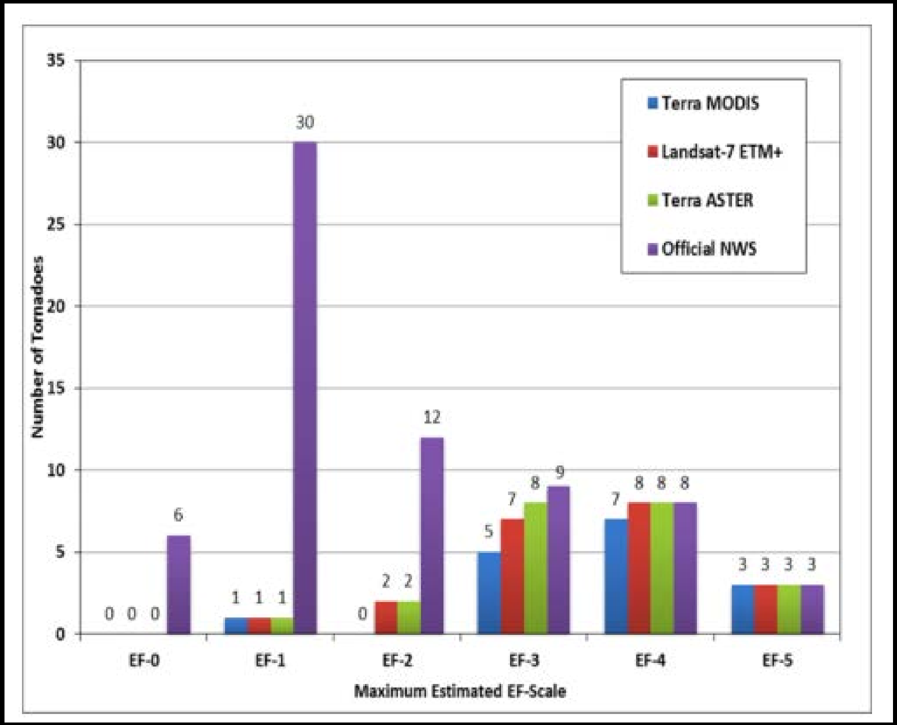
- Severe thunderstorms, including damaging winds, hail, and tornadoes, lead to vegetation scarring that can be observed from satellite, along with UAVs and other instruments.
- For example, evidence of the Tuscaloosa-Birmingham tornado of April 27, 2011 remains evident 5 years later.



Pre-event (2010) and five years of post-event Landsat 7 (striped) and Landsat 8 true color imagery near Tuscaloosa, AL highlighting the original damage track and recovery of surrounding vegetation.

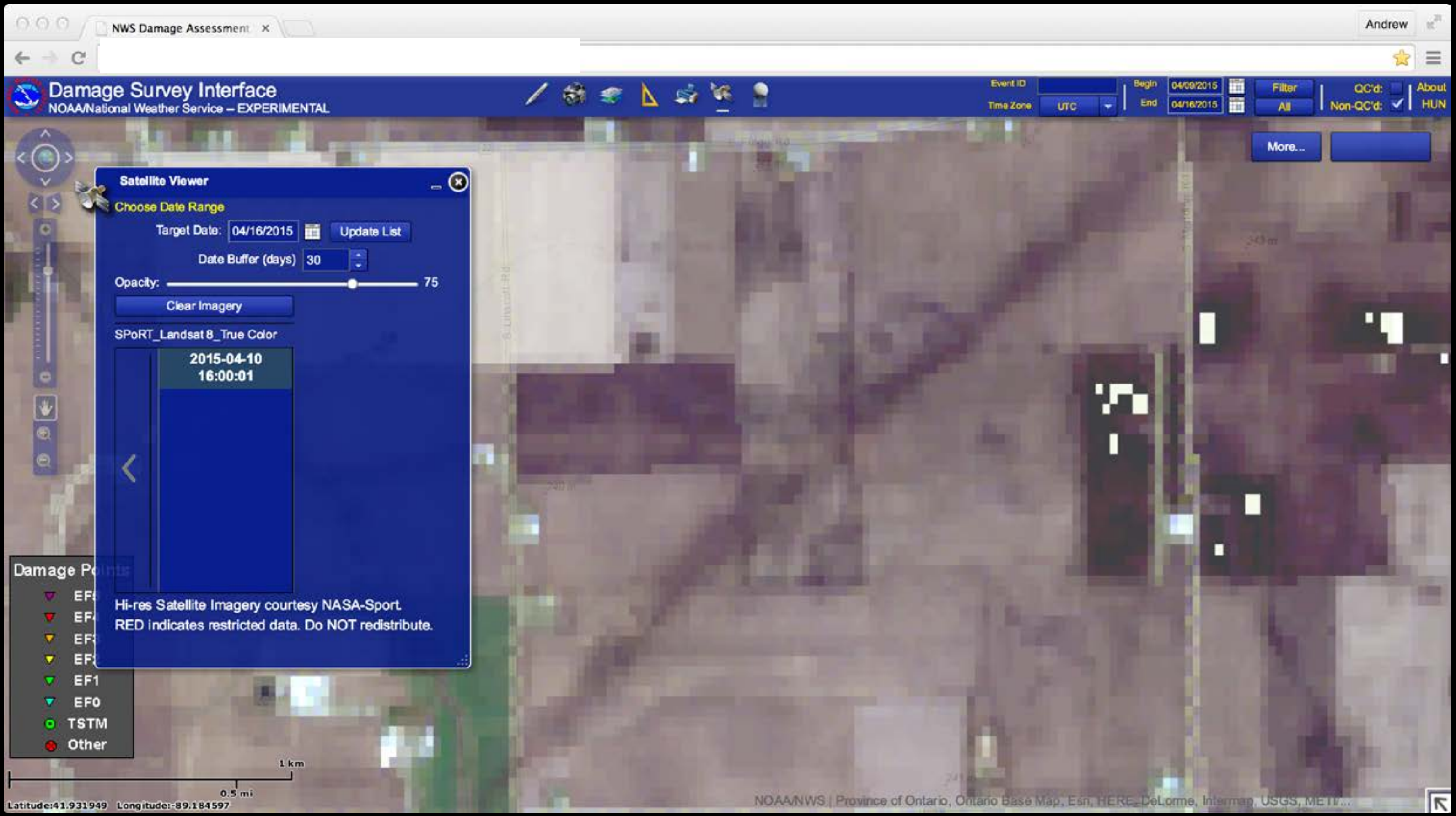
SEVERE WEATHER

- Visual identification of tornado damage tracks is possible from a variety of sensors.
- Helpful for identifying missed tracks, confirming shape in unreached areas, and informing ground-based surveys.
- Success varies somewhat with sensor resolution and damage intensity – stronger and longer tornadoes are more readily apparent.



Comparison of detections of Alabama tornadoes of April 27, 2011 from NWS official surveys and various NASA sensors, categorized by maximum EF-scale.

DAMAGE ASSESSMENT TOOLKIT



Imagery and products are provided to the NWS Damage Assessment Toolkit to support surveys and assessment. Here, a tornado from the Chicago area on April 9, 2015 and seen by Landsat 8 on April 10.

DAMAGE ASSESSMENT TOOLKIT

PUBLIC INFORMATION STATEMENT...UPDATED
NATIONAL WEATHER SERVICE CHICAGO IL
1247 AM CDT WED APR 15 2015

...NWS DAMAGE SURVEY RESULTS FOR 04/09/15 TORNADO EVENT...

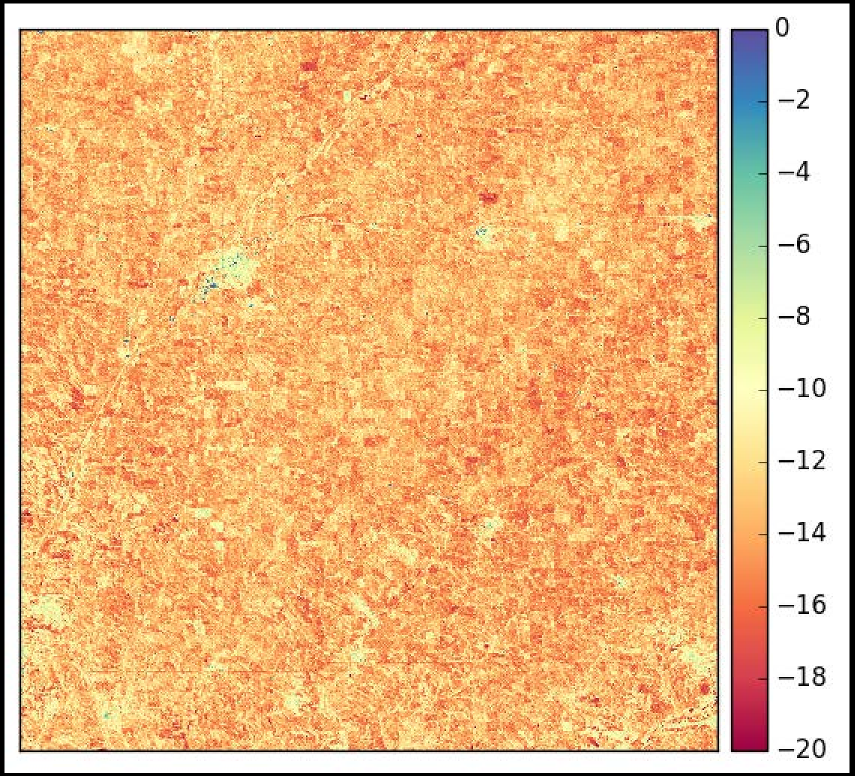
NWS METEOROLOGISTS HAVE NOW CONFIRMED SEVEN TORNADOES ACROSS NORTH CENTRAL ILLINOIS FROM THE EVENING OF APRIL 9. NWS CHICAGO WOULD LIKE TO EXPRESS APPRECIATION TO NASA SPORT FOR THE SATELLITE IMAGERY...NOAA REMOTE SENSING DIVISION FOR THE HIGH RESOLUTION AREAL PHOTOGRAPHY...THE CIVIL AIR PATROL FOR AREAL PHOTOGRAPHY...AS WELL AS THE ILLINOIS STATE POLICE AND THE MCHENRY COUNTY EMERGENCY MANAGEMENT AGENCY FOR THEIR AREAL DAMAGE PHOTOS AS WELL. ALL OF THIS REMOTE SENSING DATA ALONG WITH THE GROUND SURVEYS WERE INSTRUMENTAL IN IDENTIFYING THE TORNADO PATHS LISTED BELOW AS WELL AS THE DAMAGE INTENSITY.

THE FIRST TORNADO WAS SPAWNED OVER FAR SOUTHEAST WINNEBAGO COUNTY INTO BOONE COUNTY BY THE FIRST SUPERCELL THUNDERSTORM...WHILE THE NEXT SIX TORNADOES FORMED FROM ONE POWERFUL AND LONG DURATION SUPERCELL STORM...INCLUDING THE VIOLENT LONG TRACK EF-4 FROM NORTHERN LEE COUNTY...THROUGH OGLE AND DEKALB COUNTIES...AND ENDING IN FAR SOUTHERN BOONE COUNTY.

Satellite remote sensing, Civil Air Patrol, and other imagery can be helpful following a large outbreak.

SEVERE WEATHER

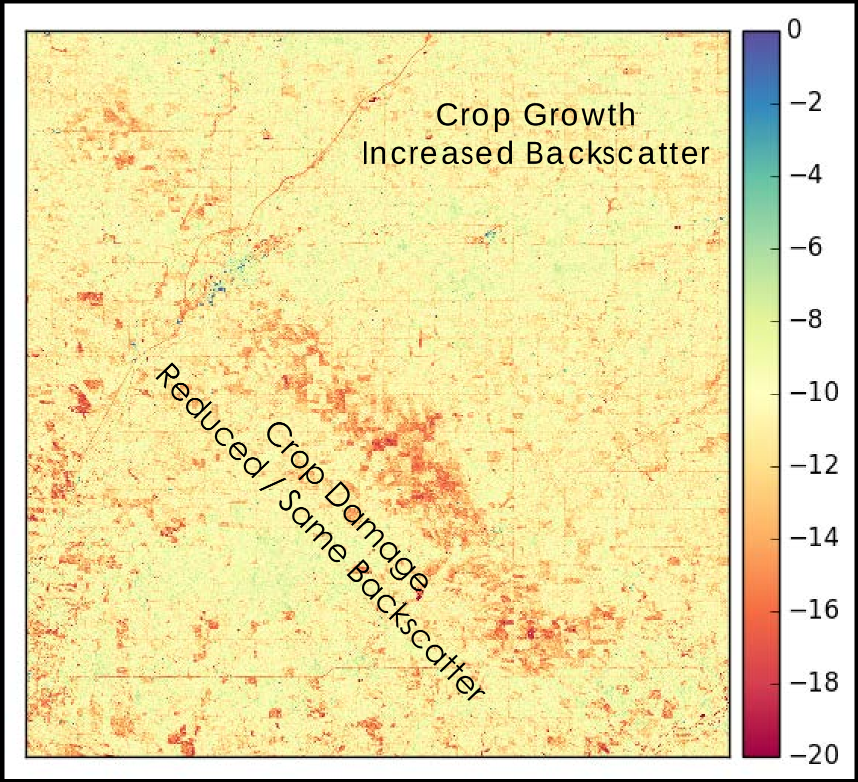
- As with flood mapping, Synthetic Aperture Radar can be helpful for identifying severe weather damage:
  - Cloud-penetrating
  - High resolution
  - Sensitive to vegetation characteristics and change, especially for shorter wavelength and varying polarization



Sentinel 1A VV backscatter in NW Iowa on June 6, 2016, prior to significant crop growth and green-up.

SEVERE WEATHER

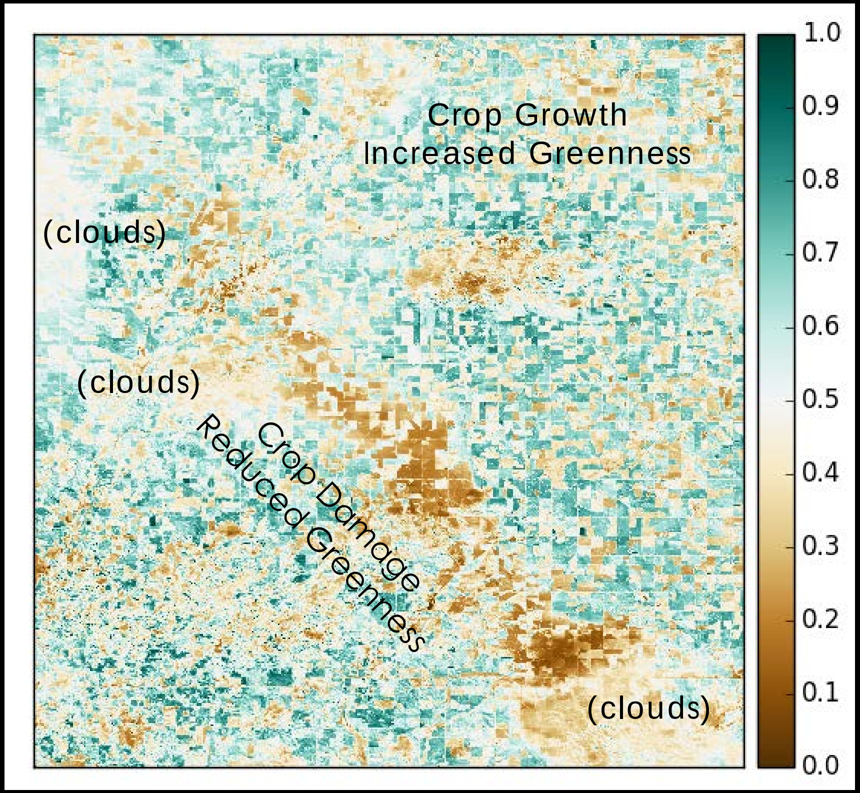
- Here, backscatter is reduced along a NW to SE corridor, corresponding to crop damage from combined wind and small to marginally severe hail.
- Anomalies can be compared against surrounding fields to better discriminate damage areas.



Sentinel 1A VV backscatter in NW Iowa on June 30, 2016, with crops damaged by a wind/hail storm.

SEVERE WEATHER

- Here, backscatter is reduced along a NW to SE corridor, corresponding to crop damage from combined wind and small to marginally severe hail.
- Landsat 8's Enhanced Vegetation Index highlights the same area as decreased vegetation greenness.



Landsat 8 Enhanced Vegetation Index identifies and confirms the same vegetation anomalies.

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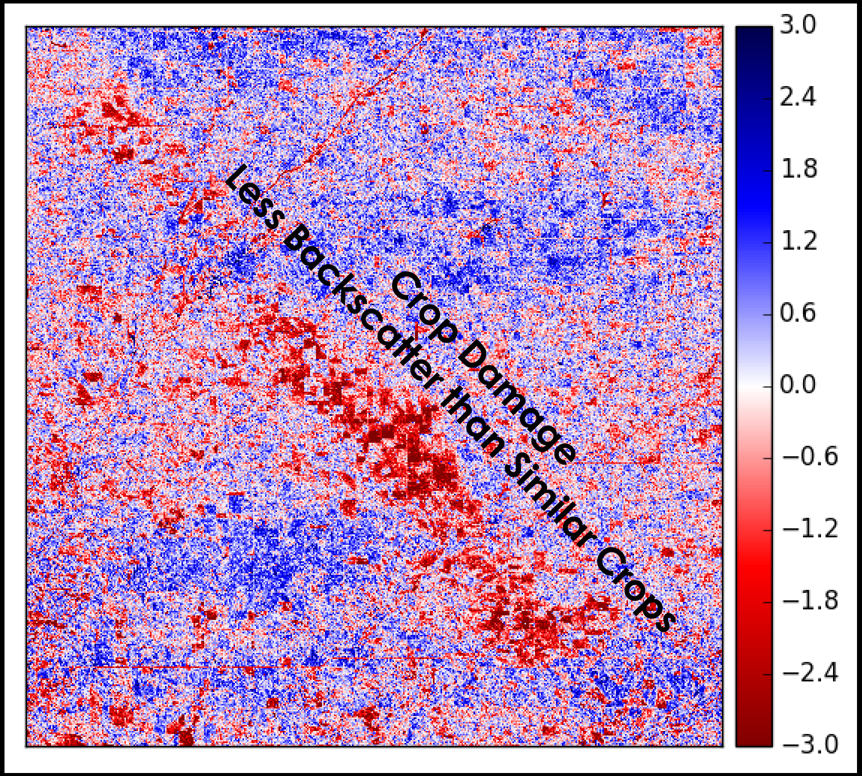

Local standardized anomaly (Z-score) for agricultural pixels when compared to immediate background. Negative values are likely damage.

SUMMARY

- NASA's constellation of current and future Earth Science satellites provide numerous opportunities for applications to weather analysis and forecasting, land surface understanding, and disaster response.
- Properly integrated into end users' decision-making process, these products can be used to inform decisions and decision support services, when provided with relevant training and end-user engagement.
- Future NASA satellites will continue to provide exciting new applications of remote sensing data to these and other challenges.